TECHNICAL NOTES

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No. 200

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GENERAL DESCRIPTION OF THE DESIGN.

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In working out a design of propellers to be made of micarta it is necessary to depart somewhat from the conventional types of propeller design so as to make the most advantageous use of the properties which are peculiar to the material. It would be possible to take the design of an ordinary wooden propeller and build it in micarta. This would give a very heavy propeller, however, which, of course, would be a very serious fault in a propeller to be used in aircraft. The resulting propeller would also be no more efficient than the corresponding wooden propeller.

The heaviest part of the wooden propeller is the hub boss. It is necessary to make this large on account of the high crushing stress imposed by the drive and also on account of the tendency to split out through the hub and bolt holes.

In micarta we are dealing with a material of enormously greater crushing strength than wood. At the same time, the grain is in only one plane in the case of micarta so that we may make the plane of the grain perpendicular to the axis of rotation and avoid any danger of splitting out through the hub boss. Of course,

* Aeronautical Engineer, Air Service, War Department.
** Material and Process Engineering Department, Westinghouse Electric and Manufacturing Company.

in the case of the wooden propeller the splitting may occur in any plane parallel to a radial line through the main portion of the blade.

The use of micarta thus permits a much smaller hub boss than the corresponding wooden propeller. This in itself makes for a considerable saving of weight.

At the same time, freedom from the tendency to split makes it possible to use thinner sections with micarta blades than is possible with most wooden blades, and as a result there is an improvement in efficiency.

It is also possible to use somewhat narrower tips with micarta propellers than with wooden ones, and this appears to be an advantage from the standpoint of efficiency in high speed propellers. If the wooden propellers are made very narrow at the tips, they become too fragile to stand the abrasion of small stones, grass, etc. On account of the greater toughness of the material, and its freedom from any tendency to split, the micarta blades may be made quite thin at the tips without impairing them from the service standpoint.

In the practical design of aircraft propellers one of the most destructive forces encountered is a form of torsional vibration usually described as flutter. This form of stress is often particularly severe because, when once started, it is apt to increase in severity due to the absence of damping.

From Fig. 11 it is obvious that the effect of the air pressure on the blade will be to cause it to twist in such a way as to increase its angle. As soon as the angle is increased the actual amount of air pressure is increased, due to the higher angle and at the same time the position of the line of resultant air pressure moves toward the leading edge; (shift of center of pressure with increase of angle) so that the twisting moment is considerably increased by a relatively small change in angle. The only force tending to restore the blade to its initial angle is the elasticity of the material. After this vibration gets under way, the energy of the oscillation continues to increase until its rate of increase is either balanced by the internal work of friction of the material or it continues to increase until failure of the part takes place.

The most obvious method of providing a damping means for this form of oscillation would be to so design the blade that the air pressure will cause the angles to decrease rather than increase. The method used in wooden propellers to approach this condition is to design the propellers with a sharply curved leading edge and nearly straight trailing edge. This method was applied in the case of the micarta propellers for the Liberty engine and for the 300 HP Wright engine (Fig. 12).

Another method of making the angles decrease under the influence of the air pressure is to make the leading edge stiffer than the remainder of the blade, so that the virtual center of gravity in torsion is moved nearer the leading edge.

An inspection of Fig. 13 will show that the effect of moving the virtual center of gravity of the section in torsion far enough forward is to cause the blade angle to decrease under the effect of the air loading. This will produce a damping effect so that the torsional oscillations are never apt to become excessive. In all of the micarta blades an attempt has been made to reach this condition by molding in small piano wires or other reinforcing material somewhat as shown in Fig. 13. As will be shown later on in this article, this method is preferable from the design standpoint to the use of an excessively curved leading edge (Fig. 14), because the great curvature of the leading edge usually introduces centrifugal bending moments which may be quite severe.

These centrifugal bending moments are particularly objectionable in reversible propellers since the bending moments due to the air forces are usually added to those due to centrifugal force when the propeller is set in the position of reverse thrust. For this reason, the blades for the reversible and adjustable propellers were made symmetrical, the centers of gravity of the various cross-sections being spaced in a radial line perpendicular to the axis of rotation. This arrangement eliminates the bending moments due to centrifugal force from the static stress analysis since all of these moments will be zero. How the centrifugal forces effect the stress when the propeller is subjected to deflection will be discussed later.

Considerable study has been given in all countries to the subject of the adjustable pitch propeller as a means of improving the performance of airplanes. With the conventional type of gasoline engine power plant, the propeller must be designed to absorb the power of the engine at the top speed of the airplane when the engine is turning at its maximum safe speed. When the airplane is standing on the ground the engine will be able to turn this propeller at only about 65% of the maximum safe engine speed while during the climb it will be able to turn the propeller at only about 90% of the maximum safe engine speed. Thus at the time of take-off, the engine is only able to develop about 85% of its maximum power, while during the climb it is able to develop only about 90% of the maximum power. By the use of adjustable pitch propellers, it is possible to slightly reduce the angles of the blades during the climb so that the engine may turn at its maximum safe speed at all times. Since the adjustable propeller involves the changing of the blade angles from the pilot's seat while the airplane is in motion, there is very little additional complication in making the change in angle great enough so that the propeller becomes a pusher instead of a tractor. This type of propeller is known as a reversible propeller. It is, of course, not used as a means of actually backing the aircraft except in the case of an airship. In the case of an airplane, the reversed propeller is used as a very powerful brake to bring the plane quickly to rest when landing in a confined space, or on very rough ground, etc. This reversing feature is of no particular value for landing on good, smooth fields, such as the usual airdromes. As a means of extending the field of the airplane, however, by permitting landing in small spaces and a better take-off from these places, the adjustable and reversible propeller offers a very promising field.

The reversible and adjustable propeller with micarta blades shown in Fig. 15, is one of the most practical devices yet worked out for this purpose. It is quite strong in all details, weighs very little more than the fixed pitch propeller, and operates so easily that the pitch may be adjusted with two fingers on the control lever when the engine is running.

The blades of these propellers are made interchangeable as to pitch and balance so that any blade may be replaced by simply screwing one blade out and screwing in a new one.

Fig. 16 shows a front view of an airplane equipped with one of these adjustable and reversible propellers with micarta blades. Fig. 17 shows a side view of the same airplane and propeller. The counterweights shown at the front of the propeller are designed so that they exactly balance the centrifugal twisting moments at all angles and speeds, thereby greatly reducing the effort required to change the pitch while the engine is running.

The ferrules into which the blades screw in Fig. 15 are provided internally with a ball thrust bearing which takes up the centrifugal force and two radial ball bearings to take care of the thrust and torque bending moments.

The ferrule is also provided with a series of 36 equally spaced holes at the outer end through which a cap screw passes into the blades to secure them from unscrewing. The cap screw hole in the blade is drilled by means of a jig in a fixed relation to the blade angles.

At the other end of the ferrule there are 12 equally spaced holes, 2 of which may be made to match with 3 of 9 equally spaced holes in the outer control ring, which is made integral with the counterweight. This patented differential arrangement gives 36 relative positions between the ferrule and control ring corresponding to the 36 holes in the outer end of the ferrule. It is thus possible to keep the control ring always in exactly the proper relation to the blade angles.

The method of adjusting the pitch is more or less obvious from the photographs and need not be described in detail.

At the cockpit there is a patented device to insure throttling while the propeller is passing through the neutral position, thus preventing the engine from racing with the propeller in neutral pitch.

In order to test the strength of the attachment to the ferrule, a series of tests on the shearing strength of threaded canvas micarta specimens was made by screwing the threaded specimen in a cylindrical metal sleeve and applying pressure in a testing machine until failure occurred by shearing of the threads. The values are tabulated in table.

All of the specimens show a shearing strength in excess of 4000 lb. per sq.in. of shearing area. Contrary to expectations, the finer threads show somewhat higher unit strength in shear than the coarser ones. All of the specimens were threaded with the buttress form of thread designed to carry load in one direction only. These tests indicate that the actual attachment of the blade has a shearing strength of about 180,000 lb. which is somewhat in excess of the tensile strength of the blade at the shank. The normal load of this part in operation is about 20,000 lb.

These detachable blades are also made up to install in fixed pitch propellers. Fig. 18 shows a propeller arranged to provide detachable and interchangeable blades for the 180 HP Wright engine, while Fig. 19 shows a three-blade propeller made up for the 300 HP Wright engine.

Many whirling tests have been run on all different types of micarta propellers. One of the most interesting tests was a run of 300 hours on the Liberty propeller, most of which was carried out at an input of 500 HP. This test was run before any of the propellers were released for service. A later series of tests was run by testing five propellers at 1000 HP input until destruction occurred. This series of tests resulted in adopting the type of hub drive shown in Fig. 20.

One of the Liberty micarta propellers equipped with this type of hub drive withstood a test of 25 hours at 1000 HP input before failure occurred.

A number of interesting flight tests have been made with the Liberty micarta propeller (Fig. 21). Fig. 22 shows a comparative test of the Liberty micarta propeller and a wooden propeller for the same engine and airplane.

The curves show that the micarta propeller gave a top speed of 2 miles per hour more than the wooden propeller while turning about 120 R.P.M. slower. In spite of the lower R.P.M. of the micarta propeller, the rate of climb for the two is about the same. At the top speed the micarta propeller shows an improvement of 7% in fuel economy, although the plane is flying 2 miles per hour faster.

In the above, an effort has been made to describe the micarta propeller designs in a semi-technical way. In the next article, an effort will be made to give some data on the designs from the standpoint of aerodynamics and stresses.

Table

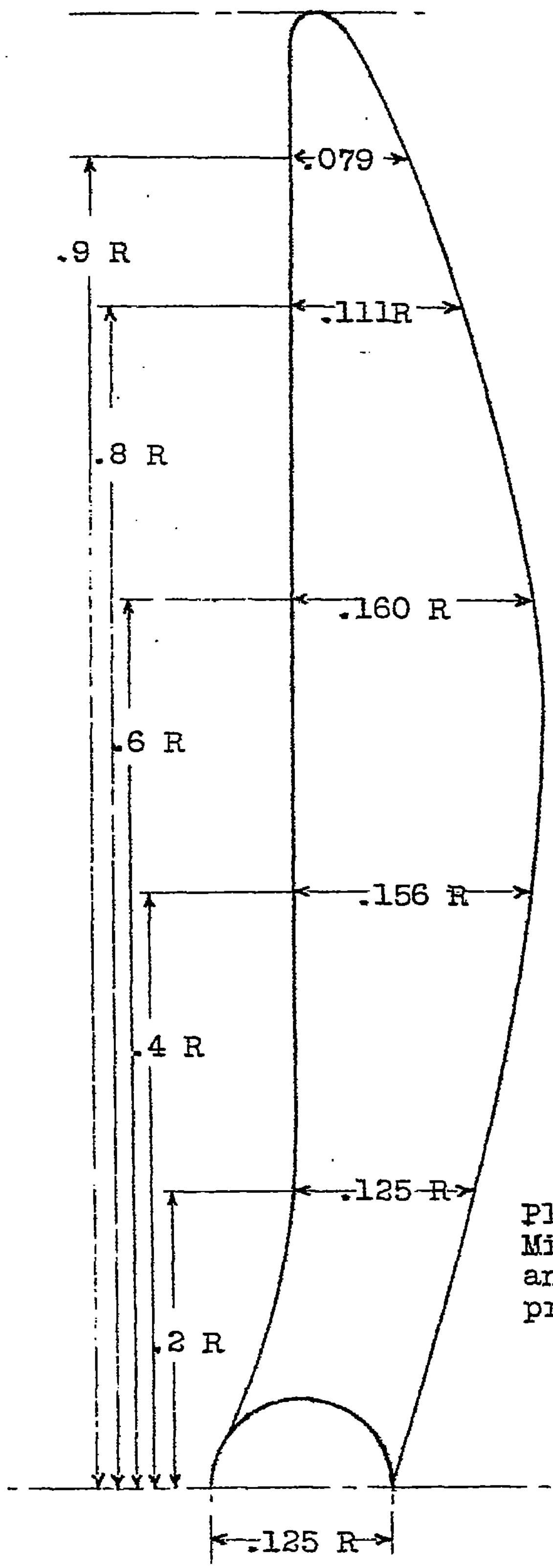
Shearing Strength of Micarta Threads.

No.	Micarta	Dwg. No.	Threads per in.	Length	Diameter outside
2	Wood	9	6	2	3
4	Canvas	11	8	2	3
5	Canvas	10	4	2	3
10	Canvas	3	2	2	4
11	Canvas	7	6	2	4
12	Canvas	6	4	2	4

Shearing Strength of Micarta Threads (Cont.)

No.	Root diameter	Thread area at root	Yield lb.	Yield sq.in.	Maximum load	Ult. Str. #per sq.in.
2	2.74	15.06	46000	3,054	85,000	5,644
4	2.80	15.39	57000	3,704	92,000	5,978
5	2.62	14.40	50000	3,472	78,700	5,465
10	3.25	17.87	55000	3,078	100,000	5,596**
11	3.74	20.56	58500	2,845	100,000	4,864***
12	3.62	19.90	37000	1,859	100,000	5,025****

** 100,000 lb. for 28 hours
*** 100,000 lb. for 15 minutes
**** 100,000 lb. for 4 minutes



Plan form of Micarta Liberty and 300 HP. Wright propellers.

Fig.12.

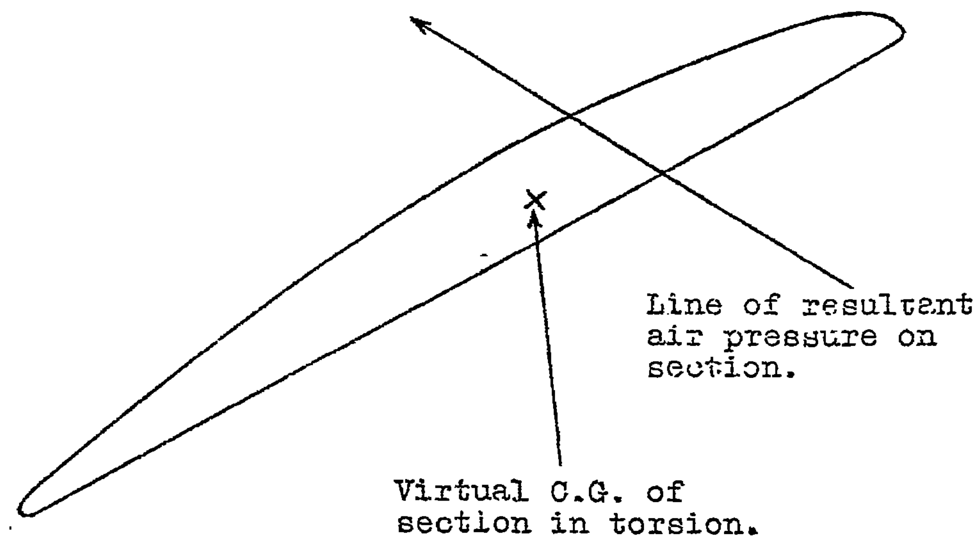

Line of resultant air pressure on section.
Virtual C.G. of section in torsion.

Fig.11.

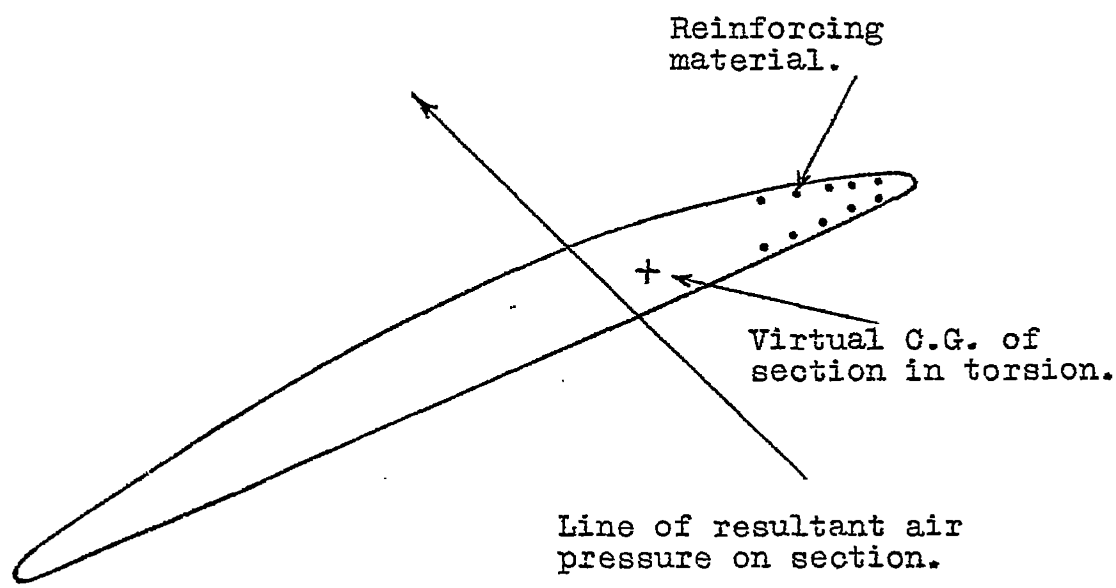

Reinforcing material.
Virtual C.G. of section in torsion.
Line of resultant air pressure on section.

Fig.13.

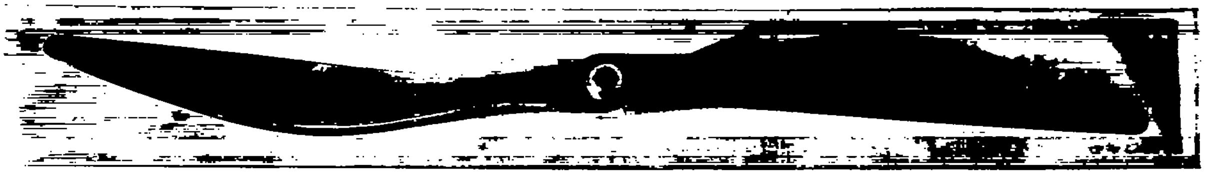


Fig. 14

Fig. 15

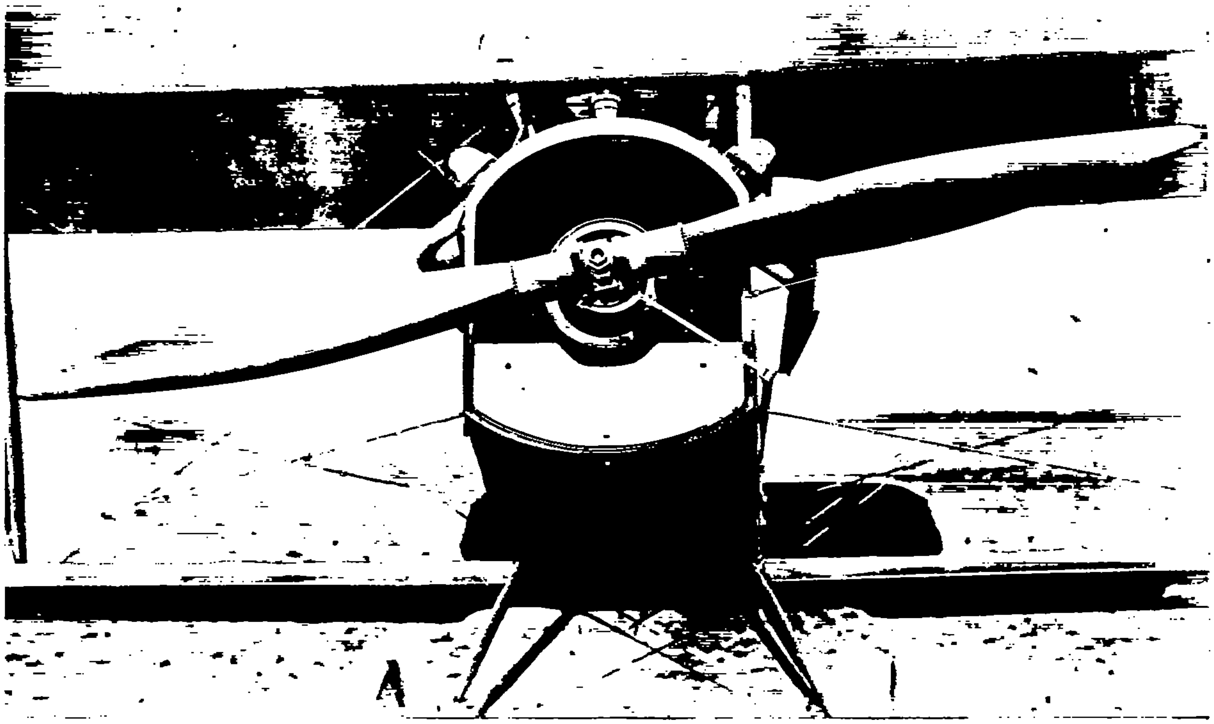


Fig. 16

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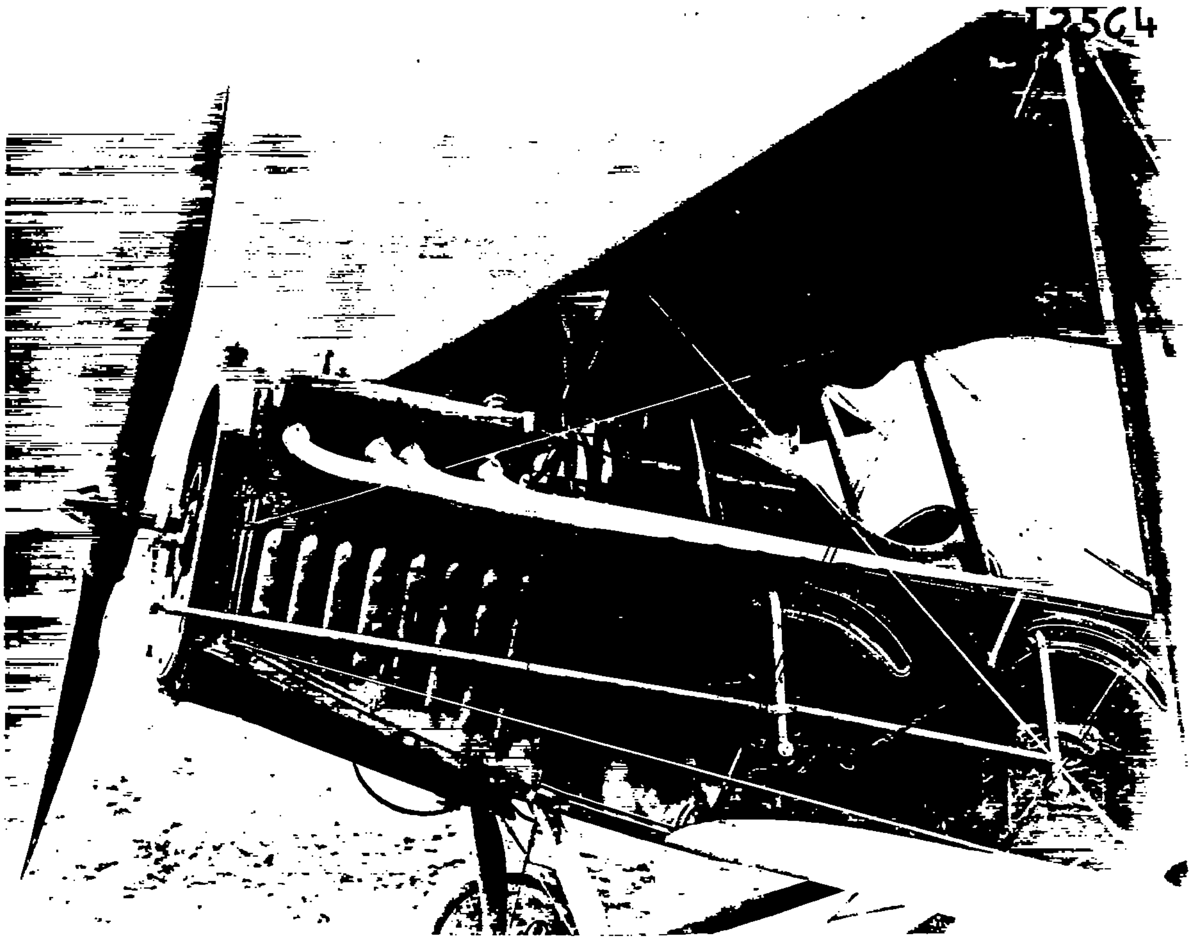

Fig. 17

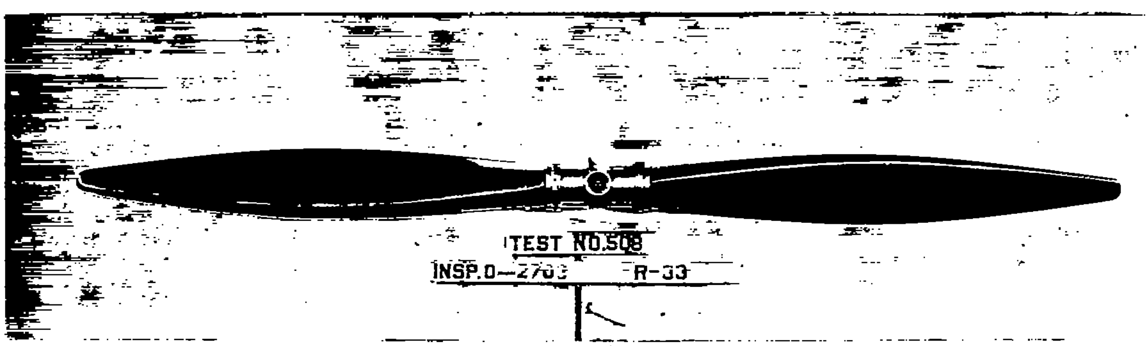

Fig. 18

Fig. 19

Fig. 20

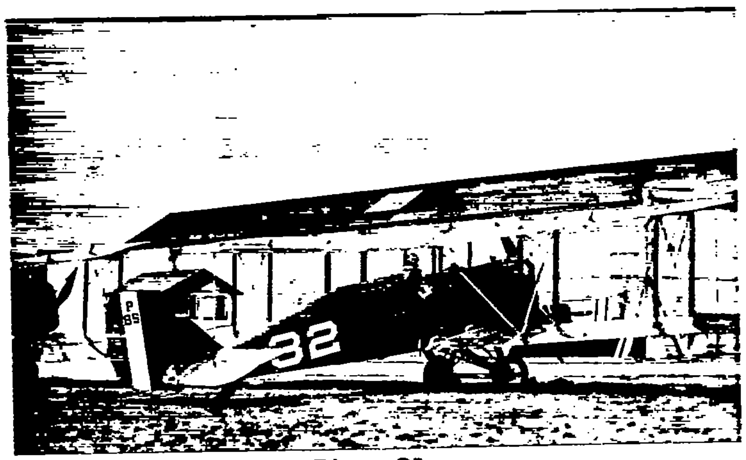

Fig. 21

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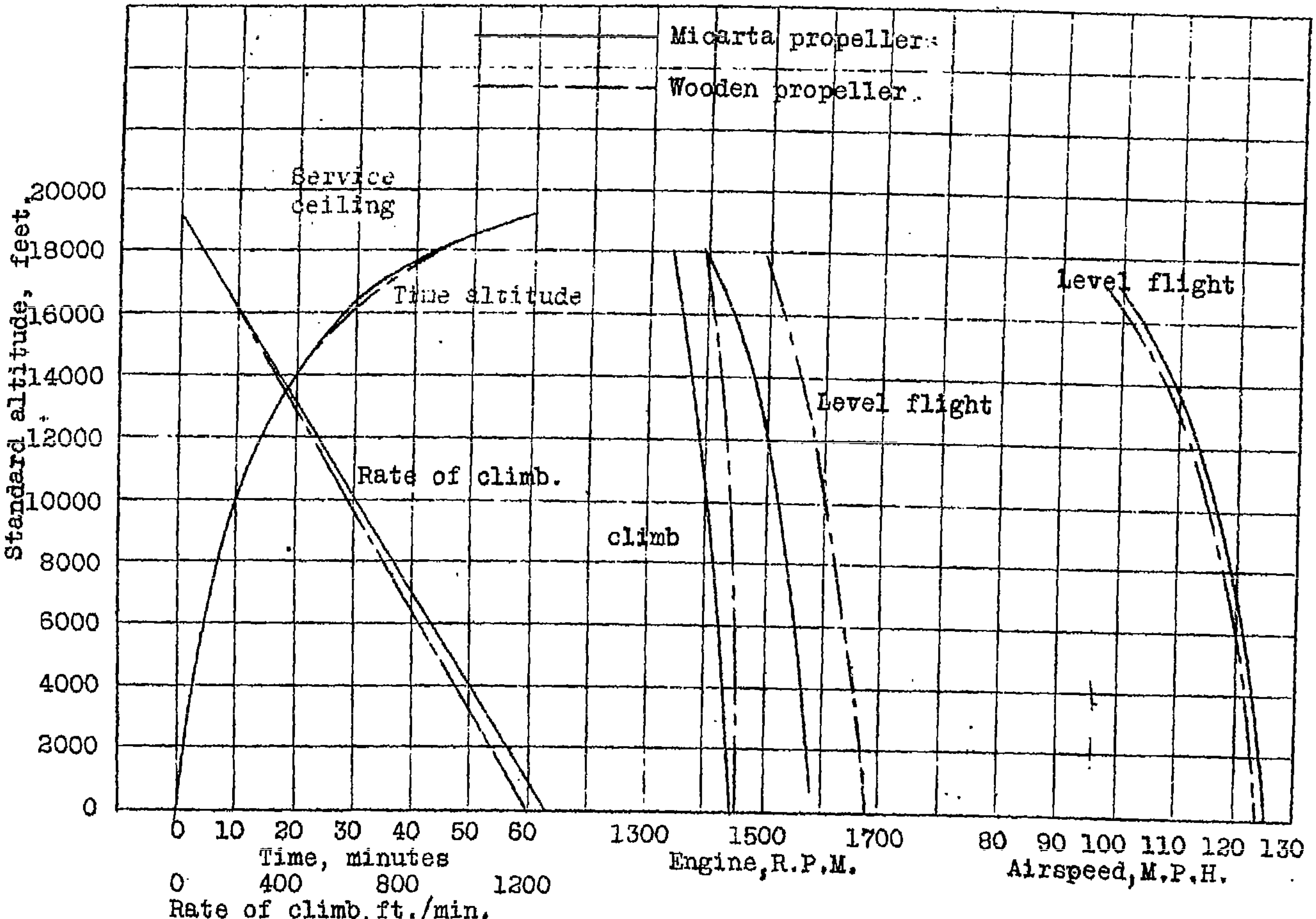

Fig.22. Comparative propeller test on DH-4.